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PHYSIOLOGICAL RESPONSES DURING SHIPBOARD FIREFIGHTING

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SUMMARY

Problem.

Studies of the physical demands of firefighting have consisted of measuring the physiological responses of firefighters in the following situations: 1) men wearing firefighting clothing/equipment when walking on treadmills in environmental chambers with air temperatures under 45°C, 2) men conducting open-air firefighting training scenarios, and 3) firefighters en route to fire scenes and involved in actual firefighting. The findings from these studies suggest a high potential for heat strain due to firefighting. Previous field investigations of physiological responses during firefighting were seriously limited because they were not conducted in extreme air temperatures and steam. Shipboard fires have been known to produce air temperatures as high as 1200°C near the fire. There are unresolved questions about the level of heat strain associated with suppression of large shipboard fires, and what constitutes realistic tolerance times.

Objective.

The primary objective was to determine the level of heat strain experienced by U.S. Navy Damage Control personnel while combating fires aboard a damage control research/firefighting ship.

Approach.

Male volunteers (n=9) experienced in firefighting were recorded for rectal temperature (T_{re}), four skin temperatures (weighted mean, T_{msk}) and heart rate (HR) during three fire test days. The physical characteristics of the subjects were: age = 36.7 ± 4.9 yrs, height = 181.2 ± 3.8 cm, weight = 81.8 ± 13.1 kg. Each subject wore the standard Navy firefighting ensemble.

Results.

During three tests, air temperatures in the compartment containing the fire to be extinguished averaged 470 ± 170°C, while air temperatures in the compartment from which the fire was fought ranged from 40 to 125°C. Prior to firefighting, physical activity while dressing in the ensemble led to a gradual increase in T_{re}, T_{msk}, and HR. During active firefighting, T_{re}, T_{msk}, and HR increased rapidly. For all tests combined, the rate of T_{msk} rise (8.73°C·hr^{-1}) exceeded the rate of T_{re} rise

($2.95°C \cdot hr^{-1}$) leading to convergence of these values. In some individuals, T_{msk} remained greater than T_{re} throughout the duration of firefighting and initial stage of recovery. Average peak values over all tests were: T_{re}, 39.2 ± 1.0°C; T_{msk}, 39.5 ± 0.9°C; body heat storage (HS), 2.02 ± 0.77 $kcal \cdot kg^{-1}$; and rate of HS during firefighting, 170 ± 92 $kcal \cdot m^{-2} \cdot hr^{-1}$. Peak HR for the three tests averaged 186 ± 13 beats per minute (bpm) or 100 ± 8 percent of age predicted maximum HR.

Conclusions.

Our findings indicate that shipboard firefighting is associated with a remarkable level of individual heat strain. During firefighting, the heat strain is characterized by: 1) increases in rectal and skin temperatures, 2) convergence of rectal and skin temperatures, 3) high peak body temperatures, 4) a high level and rate of heat storage, and 5) increases in heart rate up to and above age-predicted maximum values. The elevated physiological response to firefighting is likely due to the combined effects of the psychological stress and physical demands of firefighting, exposure to high air temperatures during firefighting, and the resistance to dry heat and evaporative heat loss offered by the firefighting ensemble. Thus, if firefighting training programs are to reflect "real" shipboard fire situations, then newer training scenarios incorporating higher thermal temperatures, as well as steam and smoke, must be developed. These findings have applications to operational training programs, generation of exposure guidelines, and development of heat strain countermeasures.

INTRODUCTION

Effective damage control operations for shipboard fires is limited to historical reports, hearsay, and narratives of past fires (Carhart and Williams, 1988). Most damage control firefighting doctrine is founded on retrospective analysis of past fires, while testing of established doctrine is confined to training center scenarios or simulated practice sessions aboard ships. Based on these limitations of live fire research, the U.S. Navy has developed a full-scale fire research and test platform, the ex-USS Shadwell (LSD-15), for the purpose of improving existing doctrines and developing new methods of shipboard firefighting.

Descriptions of the physical demands of firefighting have consisted of physiological responses to: 1) men wearing firefighting clothing/equipment when walking on treadmills in environmental chambers with air temperatures under 45°C (Duncan et al. 1979; Skoldstrom 1987; Pimental et al. 1991); 2) men conducting open air firefighting training scenarios (Romet and Frim, 1987); and 3) firefighters en route to and during actual fires (Barnard and Duncan, 1975). The findings from these studies suggest that heat strain during firefighting is potentially great.

A major limitation of previous field studies investigating physiological responses during firefighting is the absence of extreme air temperatures and steam. Shipboard fires have been known to produce air temperatures near the fire as high as 1200°C (STARK Action Follow-up Report). A major question still unresolved concerns the amount and rate of heat storage (HS) associated with suppression of major shipboard fires, and realistic tolerance times to heat exposure when exposed to potential extremes. Therefore, the purpose of this study was to record body temperatures and heart rate (HR) responses, and to determine the HS values of firefighters performing fire suppression activities during shipboard fire tests.

METHODS

Fire Tests.

The fire tests were part of the Internal Ship Conflagration Control research program sponsored by the Naval Sea Systems Command and conducted by the Navy Technology Center for Ship Safety and Survivability, Naval Research Laboratory. The tests evaluated procedures and equipment for

use in combating a post-flashover fire similar to that aboard the USS Stark (FFG-31) when struck by two Iraqi EXOCET missiles in May 1987. The tests occurred aboard the USS Shadwell (decommissioned LSD-15) located at Little Sand Island, Mobile, Alabama.

Participants and Test Subjects.

Nine males consented to have their physiological responses recorded during one of the three test fires (Table 1). From these nine subjects, a total of four subjects were used during each of the three fire tests.

Table 1. Physical characteristics of the subjects.

Subj.	Age (yrs)	Height (cm)	Weight (kg)	BSA (m^2)	Predicted HR max (bpm)
1	39	182.9	81.65	2.04	185
2	37	180.3	88.45	2.08	186
3	31	185.4	81.65	2.05	189
4	42	185.4	108.86	2.31	183
5	40	175.3	58.5	1.71	184
6	31	180.3	77.11	1.96	189
7	32	182.9	83.91	2.06	189
8	44	175.3	79.38	1.96	182
9	34	182.9	77.11	1.98	188
Mean (±SD)	36.7 (±4.9)	181.2 (±3.8)	81.85 (±13.1)	2.02 (±0.16)	186 (±3)

BSA = Body Surface Area

Procedures and Physiological Measurements.

Prior to the beginning of the fire test series, all subjects completed a medical history questionnaire. Each subject acknowledged his consent to participate following explanation of all experimental procedures and methods, and by reading and signing an informed consent.

Prior to the fire tests, each subject inserted a rectal thermistor to a depth of 20 cm. In addition, skin thermistors were placed over the right shoulder, chest, and middle of the right thigh and calf. Rectal and skin temperatures, as well as HR, were recorded continuously by a

Squirrel data logger (Science/Electronics, Miamisburg, OH 45342). The data logger was worn underneath the firefighting ensemble.

Age-predicted maximum HR was calculated from a regression equation for men of above average fitness (Cooper et al. 1977). Mean skin temperature was calculated from individual skin temperatures using a weighted regression equation (Ramanathan, 1964). Mean body temperature (T_{mb}) was calculated according to a weighted regression equation (Burton, 1935) using T_{re} and T_{msk}. Body heat content (BHC) was calculated by multiplying 0.83 (specific heat of the body in $kcal \cdot kg^{-1} \cdot {}^{o}C^{-1}$) by T_{mb} and body weight in kilograms. BHC was standardized to body weight (kg). Body surface area (BSA) was calculated using a height and weight regression equation by DuBois (Carpenter, 1964). HS (as indicated with $kcal \cdot kg^{-1}$) equaled the difference in BHC from resting baseline to peak value. The rate of HS was calculated as the change in BHC ($kcal \cdot m^{-2} \cdot hr^{-1}$) during firefighting.

During the three fire tests, body temperatures and HR response were recorded in four subjects per test engaged in fire suppression. Equipment problems prevented recording of T_{re} in Subject 5 during Tests 2 and 3, and HR in Subject 5 during Test 2 and Subject 8 during Test 3; these values are not included in this report.

Statistical analysis included calculation of means and standard deviations. Coefficients of determination were calculated to assess the impact of increases in skin temperature on the rise in heart rate during firefighting.

Fire Test Scenario.

Three fire tests were conducted on three consecutive days. Each fire test was initiated, supervised, and declared terminated by a fire test director. All of the fire tests were identical in setup and initiation. All fires occurred in a section of the port wing wall (Figure 1). The objective of the firefighting scenario was to contain and extinguish a Class A material fire in the #2 Radar and Interior Communications Equipment Room (RICER 2). On the fire test days, all participants and subjects attended a pre-fire meeting and developed a fire containment/suppression scenario. Subjects were then prepared for

recording of physiological responses. After fire ignition and sounding of the shipboard damage control alarm, participants and subjects moved quickly to a damage control locker to dress in the standard Navy firefighting ensemble (single-piece heavy insulated fire retardant suit, gloves, rubber boots, flash hood, hard helmet, and oxygen-breathing apparatus). After dressing, participants and subjects performed activities in preparation for firefighting. Then, upon verbal command from the fire test director, participants and subjects entered various ship compartment areas to commence firefighting activities. Termination of the test was followed immediately by a post-fire brief to analyze the fire suppression procedures.

Each day the physiological responses to firefighting reflect the temperature of the fire, duration of the firefighter in the #1 Radar and Interior Communications Equipment Room (RICER 1), and the firefighting techniques used to attack the fire; e.g., the type of fire hose nozzle used, the amount of water applied, the type of desmoking and ventilation techniques used. Each of these variables have an independent as well as synergistic influence on the level of heat stress in the firefighting compartment. The following description of the firefighting activities used over the three days will assist in the interpretation of the physiological differences shown in the Results Section.

Firefighting Activities Observed During Day 1.

Prior to the commencement of firefighting, the average air temperature in RICER 1 was 38°C. During this test, the RICER 1 firefighter team made three horizontal attacks on the RICER 2 fire through the partially blocked door connecting RICER 2 with RICER 1. During the first attack, the team applied water indirectly to the forward bulkhead to RICER 2 using a 0.6 cm (1.5 inch) fire hose. However, this procedure generated steam which completely engulfed RICER 1, increased upper air temperatures to as high as 125°C (average 76°C), and temporarily forced the team to leave the RICER 1 compartment. During the second attack, the team sprayed large amounts of water onto the forward bulkhead of RICER 2 and ceiling of RICER 1, but this again produced steam and high temperatures which drove the team back. During the third attack, the team applied less water to the RICER 2 forward bulkhead which created the opportunity to apply water indirectly to the Class A fire

around the partially blocked RICER 2 door. However, the team did not succeed in extinguishing the fires in RICER 2.

Firefighting Activities Observed During Day 2.

Prior to the start of firefighting, the average air temperature in RICER 1 was 32°C. Firefighting in RICER 1 began with the hanging of smoke curtains over all doorways to prevent the escape of heat and smoke, and the positioning of fans in the lower deck areas to reduce smoke, steam, and heat from adjoining compartments. The RICER 1 team then applied water indirectly to the Class A fire in RICER 2. However, this generated large volumes of smoke and steam which moved into RICER 1 and drove upper air temperatures again to 125°C (average 66°C). The team compensated by rotating the nozzleman. However, the fire was eventually extinguished when another firefighting team penetrated the Communications Information Center deck and vertically applied water directly onto the fire from above.

Firefighting Activities Observed During Day 3.

During this test, the start of firefighting in RICER 1 occurred in stratified air temperatures ranging from 28°C to 66°C (average 44°C). The temperature of the bulkhead walls interfacing the Class A fire averaged 238°C. Prior to attacking the fire, the RICER 1 firefighting team hung a smoke curtain over the forward bulkhead door to RICER 2. The team then applied a small amount of water to this wall to reduce the wall temperature while minimizing the buildup of steam. This procedure was followed by the application of water directly to the fire through the forward bulkhead door to RICER 2. Simultaneously, another firefighting team cut two holes in the Communications Information Center deck above RICER 2, which allowed venting of steam and hot gases, and direct application of water to the Class A fire.

RESULTS

Resting Baseline Response.

For Tests 1, 2, and 3, the mean resting response prior to dressing in the firefighting ensemble was: $T_{re} = 37.3 \pm 0.2°C$, $T_{msk} = 35.3 \pm 0.6°C$, and HR = 87 ± 10 bpm.

Responses to Active Firefighting.

The RICER 1 air temperatures during fire tests 1, 2, and 3 are shown in Figure 2. Peak T_{re}, T_{msk}, and HR responses were highest for Day 1 and then gradually declined over the next two tests (Figures 3, 4, and 5). For all fire tests combined, the rate of increase in T_{re} averaged 2.95°C·hr^{-1}, while the rate of increase in T_{msk} averaged 8.73°C·hr^{-1}. As a result, T_{re} reached an average of 39.2 ± 1.0°C, while T_{msk} peaked at an average of 39.5 ± 0.9°C (Table 2). Peak HS averaged 2.02 kcal·kg^{-1}, while the rate of HS averaged 170 kcal·m^{-2}·hr^{-1} (Table 3). During all tests, firefighting produced rapid increases in HR which peaked at 186 ± 13 bpm. In some individuals, peak HR exceeded the age-predicted maximum HR (Table 2).

During Day 1, the average firefighting time in RICER 2 equaled 25.2 ± 9.9 minutes. Firefighting increased T_{re} and T_{msk} to peak values of 39.9 ± 1.2°C and 40.0 ± 1.0°C, respectively. However, a peak T_{re} of 41.6°C and peak T_{msk} of 41.1°C was recorded for Subject 5. During firefighting, increases in T_{msk} were associated with increases in HR (R^2=0.88; $p<0.05$). The peak HR for Subjects 1, 4, and 8 reached a peak mean value of 200 ± 4 bpm equaling 109 ± 3 percent of age-predicted maximum HR. The rate of increase in T_{msk} (11.79 ± 7.2°C·hr^{-1}) exceeded the rate for T_{re} (3.78 ± 1.8°C·hr^{-1}), and eventually produced convergence of these temperatures. For all subjects, HS averaged 1.99 ± 0.46 kcal·kg^{-1} (Table 3). During firefighting, the rate of increase in HS averaged 224 ± 111 kcal·m^{-2}·hr^{-1}.

During Day 2, the average firefighting time in RICER 2 equaled 27.8 ± 11.4 minutes. Firefighting elevated T_{re} and T_{msk} to peak values of 38.4 ± 0.2°C and 39.9 ± 0.6°C, respectively. The rate of increase in T_{msk} (9.15 ± 5.2°C·hr^{-1}) exceeded the rate for T_{re} (2.76 ± 1.2°C·hr^{-1}) and eventually led to convergence of these temperatures. During firefighting, increases in T_{msk} were moderately associated with increases in HR (R^2=0.60; $p<0.05$). The peak mean HR for Subjects 2, 6, and 9 reached 184 ± 10 bpm, which was 98 ± 6 percent of age-predicted maximum HR. However, the peak HR for Subject 5 reached 199 bpm, or 108 percent of his age-predicted maximum HR. Firefighting produced an average HS of 1.72 ± 0.49 kcal·kg^{-1}, and the rate of increase in HS averaged 191 ± 26 kcal·m^{-2}·hr^{-1}.

During Day 3, the average firefighting time in RICER 2 equaled 41.2 ± 3.5 minutes. Firefighting led T_{re} and T_{msk} to peak values of 38.9 ± 0.1°C and 38.7 ± 0.2°C, respectively. The rate of increase in T_{msk} (5.25 ± 2.11°C·hr^{-1}) exceeded the rate for T_{re} (2.34 ± 0.6°C·hr^{-1}), which eventually lead to convergence of these temperatures. During firefighting, increases in T_{msk} coincided with increases in HR (R^2=0.91; $p<0.05$). The peak mean HR for Subjects 3, 5, and 7 reached 174 ± 10 bpm, which was 93 ± 7 percent of age predicted maximum HR. Firefighting produced an average HS of 1.72 ± 0.38 kcal·kg^{-1}. During firefighting, the rate of HS equaled 78 ± 13 kcal·m^{-2}·hr^{-1}.

Table 2. Peak rectal temperature (T_{re}), weighted mean skin temperature (T_{msk}), and heart rate (HR) responses (bpm and percent of age-related predicted maximum rate) during firefighting.

	Subj.	T_{re} Peak (°C)	T_{msk} Peak (°C)	HR Peak (bpm)	Pred. HR max (%)
Test 1	**1**	**39.6**	**40.0**	**201**	**109**
(T_a=76°C)	**4**	**38.7**	**38.7**	**195**	**106**
	5	**41.6**	**41.1**	**---**	**---**
	8	**39.8**	**40.4**	**204**	**112**
Mean (±SD)		39.9 (±1.2)	40.0 (±1.0)	200 (±4)	109 (±3)
Test 2	2	38.6	40.0	179	96
(T_a=66°C)	5	----	39.9	199	108
	6	38.4	40.4	181	96
	9	38.3	39.2	177	94
Mean (±SD)		38.4 (±0.2)	39.9 (±0.5)	184 (±10)	98 (±6)
Test 3	3	39.1	38.9	183	97
(T_a=44°C)	5	----	38.4	179	97
	7	38.8	38.8	161	85
	8	38.9	38.7	---	---
Mean (±SD)		38.9 (±0.1)	38.7 (±0.2)	174 (±10)	93 (±7)
All Tests					
Mean (±SD)		39.2 (±1.0)	39.5 (±0.9)	186 (±13)	100 (±8)

T_a = Average compartment temperature.

Table 3. Peak body heat storage (HS, $kcal \cdot kg^{-1}$) and the rate of body heat storage (rate HS_{FF}, $kcal \cdot m^{-2} \cdot hr^{-1}$) during firefighting (FF).

	Subj.	HS Peak ($kcal \cdot kg^{-1}$)	HS_{FF} Rate ($kcal \cdot m^{-2} \cdot hr^{-1}$)
Test 1	1	2.08	240
(T_a=76°C)	4	1.49	78
	5	3.9	349
	8	2.41	229
Mean (±SD)		1.99 (±0.46)	224 (±111)
Test 2	2	2.08	207
(T_a=66°C)	6	1.91	161
	9	1.16	204
Mean (±SD)		1.72 (±0.49)	191 (±26)
Test 3	3	1.74	91
(T_a=44°C)	7	1.33	65
	8	2.08	79
Mean (±SD)		1.72 (±0.38)	78 (±13)
All Tests			
Mean (±SD)		2.02 (±0.77)	170 (±92)

T_a = Average compartment temperature.

DISCUSSION

HR Response to Firefighting.

Active firefighting produced high HR responses which, in some instances, exceeded 200 bpm. The high HR values recorded by our firefighters are comparable to those reported for men engaged in firefighting (Barnard and Duncan 1975; Romet and Frim 1987) and walking on treadmills wearing firefighting clothing (Duncan et al. 1979; Pimental 1991; Skoldstrom 1987). Since the movements of our firefighters were confined to the RICER 1 compartment and adjoining passageway, the rapid increases in HR during firefighting are likely the result of the perceived psychological stress and the sustained overall body muscular

contractions (Mitchell, 1990) while holding the fire hose and maintaining body position in both bent knees and standing positions. Thus, our findings clearly indicate that shipboard firefighting in high air temperatures can produce increases in HR up to maximum predicted values.

During firefighting, increases in T_{msk} and HR occurred together. Coefficients of determination (R^2) based on the relation between HR and T_{msk} during actual firefighting ranged from 0.60 to 0.91 for the three tests. Exposure to high air temperatures increases skin temperatures, and leads to an increase in body heat when air temperature exceeds core temperature. The increase in body heat stimulates an increase in skin blood flow. However, the increase in skin blood flow reduces central venous pressure, which, in turn, lowers cardiac filling pressure and stroke volume (Rowell et al. 1969). Since heat dissipation is dependent upon the level of skin blood flow, HR increases in an attempt to maintain cardiac output, and hence, skin blood flow. Furthermore, heat dissipation is hindered when any protective overgarment is worn. Because the firefighting ensemble is a semi-impermeable garment with high insulative properties, these factors exacerbate the thermoregulatory problem of heat transfer confronting naval firefighters. Thus, the progressive increase in HR and skin blood flow during firefighting in the protective ensemble reflects, in part, a greater level of cardiovascular strain when compared to wearing no protective overgarment.

Body Temperature Responses to Firefighting.

Previous studies examined rectal and mean skin temperature responses in men dressed in firefighting protective clothing during fire training in open air or during work/rest cycles in heat chambers. Romet and Frim (1987) reported that firefighters who engaged in open air (16°C) fire training sessions had T_{re} in the range of 38.0°C to 38.8°C, and T_{msk} ranging from 32.5°C to 38.03°C. Duncan et al. (1979) reported that when men wore firefighter's clothing and exercised for 15 minutes in 42°C air temperature, T_{re} increased 0.6°C, and T_{msk} increased 2.3°C. Pimental et al. (1991) reported an average increase of 1.4°C T_{re} to 38.8°C; while T_{msk} averaged 99.4°F at the end of exercise for firefighters performing work/rest cycles for two hours in a heat chamber (32°C, 65 percent rh). Skoldstrom (1987) reported that when firemen were dressed in protective clothing and walking 60 minutes on a treadmill in 45°C, T_{re} and T_{msk} were

below 39.0°C and 38.5°C, respectively. In comparison, the high rates of increase and high peak body temperatures observed in our firefighters are greater than those reported by these investigators. Thus, shipboard firefighting in the standard Navy firefighting protective ensemble can lead to rapid increases in core and peripheral body temperatures, which can attain very high values.

In all subjects performing firefighting the rate of increase in T_{msk} exceeded the rate of T_{re} increase, resulting in convergence of these temperatures. In some individuals, T_{msk} remained equal to or greater than T_{re} for up to 25 minutes of firefighting and recovery. The convergence of T_{re} and T_{msk} suggests that heat content is becoming uniform between the body core and periphery. T_{re} and T_{msk} continued to increase after convergence, with the increase in T_{msk} exceeding the rise of T_{re}. This indicates a continuance of HS with more storage of heat in the periphery than in the core. However, no heat illness or injury or complications were observed in any participants or subjects as a result of these fire tests. Thus, our findings suggest that convergence of T_{re} and T_{msk} during firefighting are not a prelude to termination of physical activity. Pandolf and Goldman (1978) interpreted the convergence of rectal and skin temperatures to mean that onset of heat illness was imminent. However, there are marked differences between our field study and the laboratory study of Pandolf and Goldman (1978). These differences include: state of subject heat acclimation, environmental temperature and humidity conditions, type of protective overgarments, and length of heat exposure.

Physical limitations to firefighting may be better explained by the magnitude and rate of increase of HS. The rate of HS was substantially different between our more acute, high heat study, and the moderate, steady-state heat exposure study of Pandolf and Goldman (1978). Consequently, caution should be used when interpreting the thermal convergence data from our study with the intent to develop a criterion measure of heat tolerance as proposed by Pandolf and Goldman.

<u>HS as a Result of Firefighting</u>.

It has been postulated that tolerance to heat is dependent upon the development of a maximum HS. Blockley et al. (1954) reported HS of 1.86 $kcal \cdot kg^{-1}$ for men resting in air temperatures ranging from 60°C to 120°C

(140-270°F), while Shvartz and Benor (1972) reported voluntary termination from exercise and heat stress when HS reached values of 2.12 $kcal \cdot kg^{-1}$.

During the first test, increases in HS averaged 1.99 $kcal \cdot kg^{-1}$ (Table 3). These high values suggest that our firefighters may have been at or near their upper limit of HS. Lower HS was observed during the second and third tests, thereby, suggesting that our firefighters may have been able to continue firefighting a while longer.

The rate of HS is related to heat tolerance (Brockley et al. 1954; Craig et al. 1954; Shvartz and Benor 1972; Henane et al. 1979). For Test 1, firefighting activities in RICER 1 was associated with a rate of HS of 224 $kcal \cdot m^{-2} \cdot hr^{-1}$. This rate approaches the value of 240 $kcal \cdot m^{-2} \cdot hr^{-1}$ reported by Shvartz and Bencr (1972) for men wearing vapor-impermeable clothing and exercising to exhaustion in air temperatures ranging from 25°C to 50°C. The rates of HS for the three tests when compared with the recommended minimum heat exposure tolerance times of Brockley et al. (1954) suggests firefighting tolerance times from 10 to 37 minutes, which is close to the range of cessation times of 25 to 40 minutes for these fire tests. The concept that limitations in firefighting are related to attainment of a high BHC or high rate of HS could be used to develop exposure guidelines for firefighters.

Our findings suggest that shipboard firefighting is associated with a remarkable level of individual heat strain. Importantly, the level of heat strain can exceed the heat strain developed as reported for firefighting training scenarios in open-air environments. These findings would be applicable to damage control training programs. Thus, if firefighting training programs are to reflect "real" shipboard fire situations, then newer training scenarios incorporating higher thermal temperatures, as well as steam and smoke, must be developed.

The findings from this study of shipboard firefighting raise the question of how to best prevent heat strain during shipboard firefighting operations. Previous research has shown that heat strain can be effectively reduced by vests filled with reusable "frozen gel blocks" and worn over the torso (Banta and Braun 1992; Pimental and Avellini 1989).

However, more research is needed to determine the feasibility of passive cooling systems for use during shipboard firefighting.

SUMMARY

We have documented the physiological strain of firefighting during actual shipboard fires. Dressing in the standard Navy firefighting ensemble and equipment, and performing firefighting activities, produced a high level of individual heat strain when air temperatures in the firefighting compartment reached 125°C. The heat strain during firefighting is characterized by: 1) increases in T_{re} and T_{msk}, 2) convergence of T_{re} and T_{msk}, 3) high peak body temperatures (T_{re}, T_{msk}), 4) a high level and rate of HS, and 5) increases in HR up to and above age-predicted maximum HR values. Firefighting tolerance may be related to the magnitude and rate of HS. The elevated physiological response to firefighting is likely due to the combined effects of the psychological stress and physical demands of firefighting, exposure to high air temperatures during firefighting, and the resistance to dry heat and evaporative heat loss offered by the firefighting ensemble. These findings have application for the generation of guidelines for heat exposure and work/rest cycles during firefighting, development of operational training programs, and the use of heat strain countermeasures.

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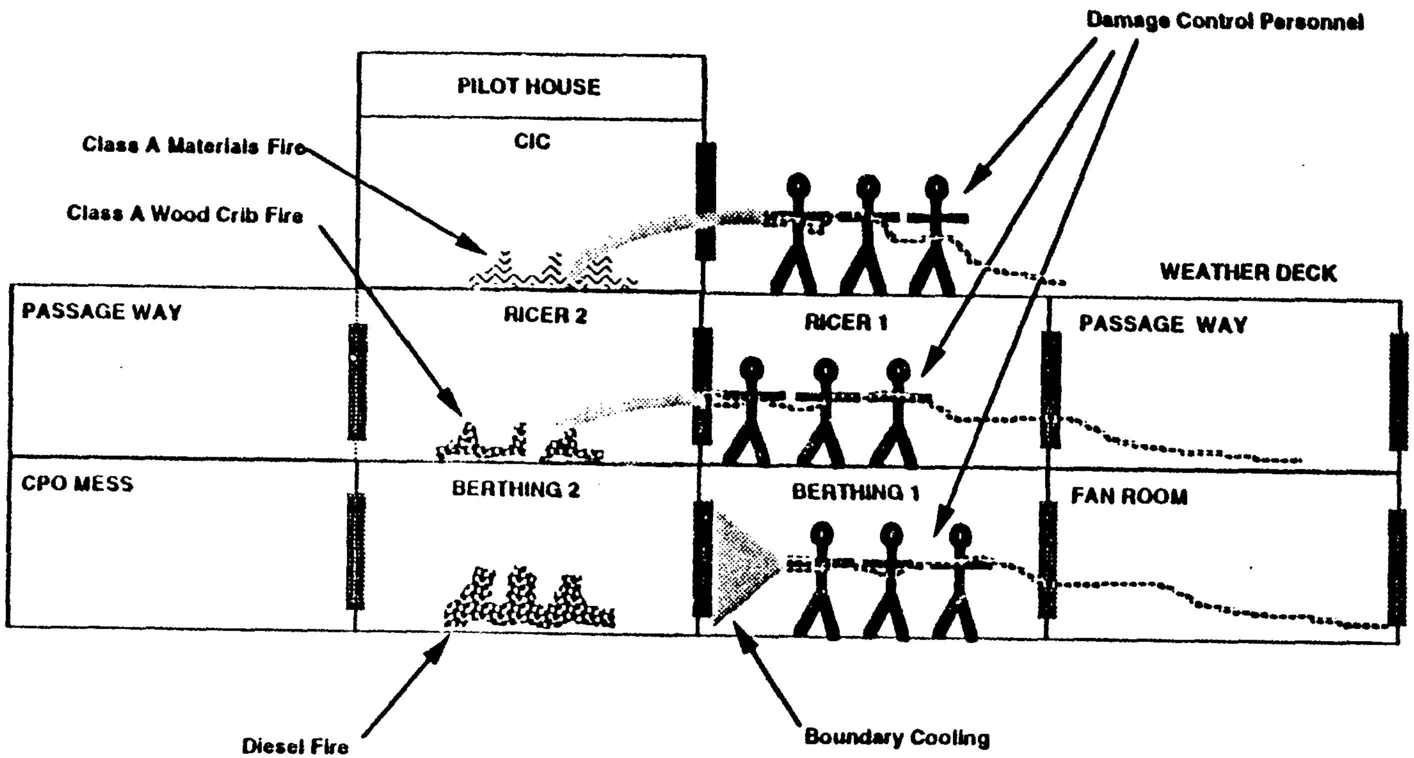

Fig. 1. Ex - USS Shadwell Port Wing Wall Fire Test Zone.

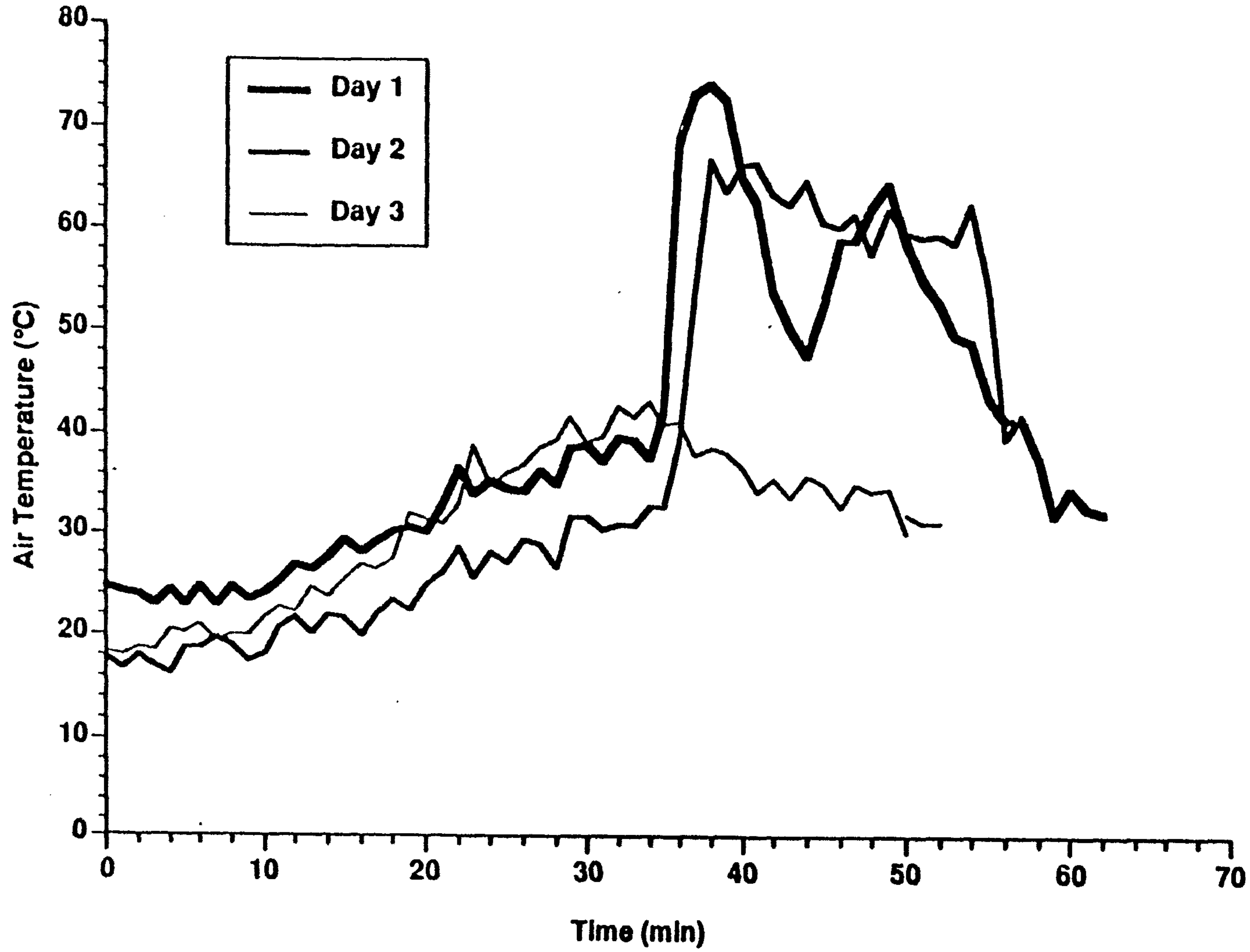

Fig. 2 Mean RICER 1 Air Temperatures During Test Days 1, 2, and 3.

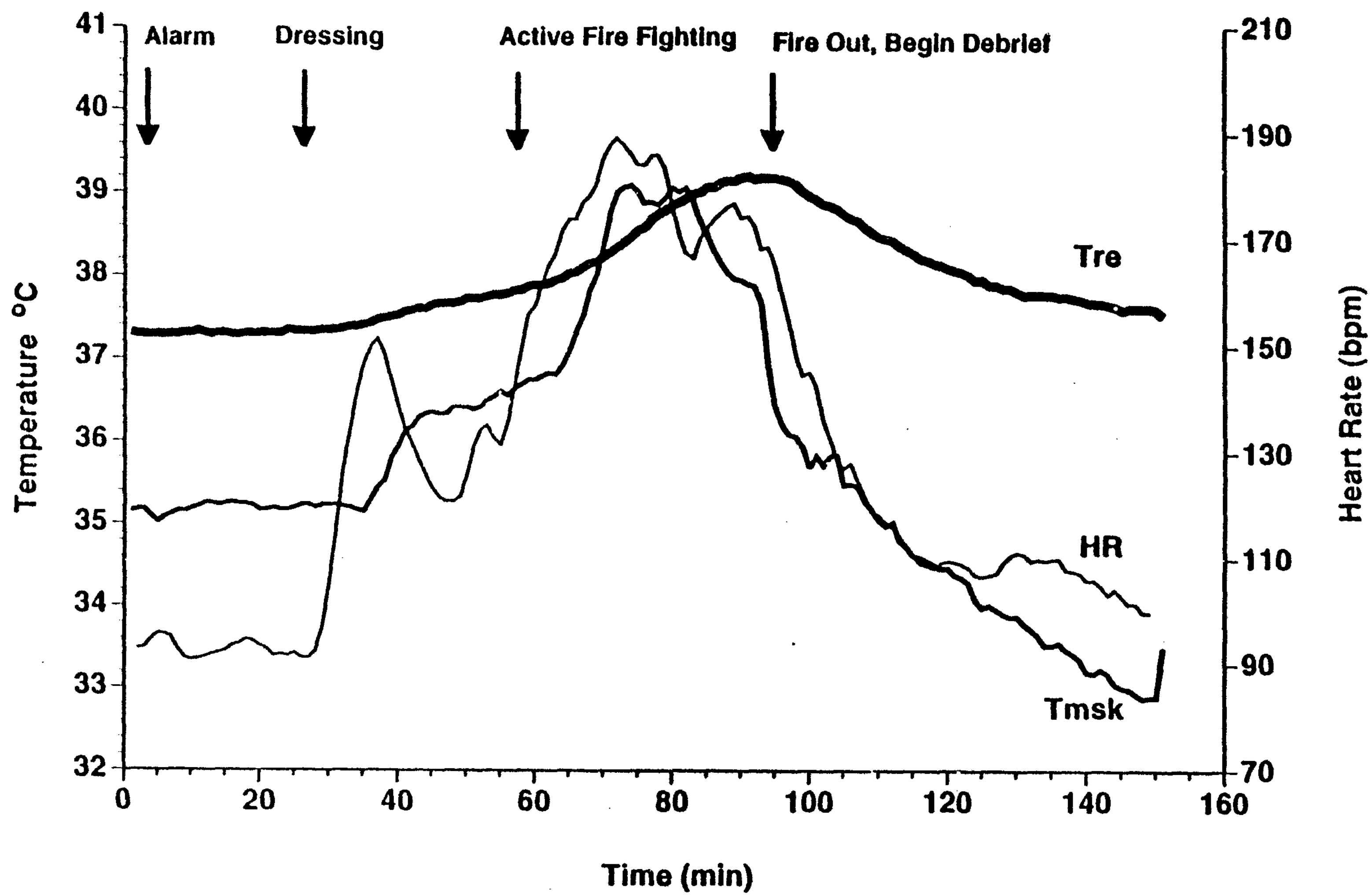

Fig. 3. Mean physiological responses for Day 1 (n=3).

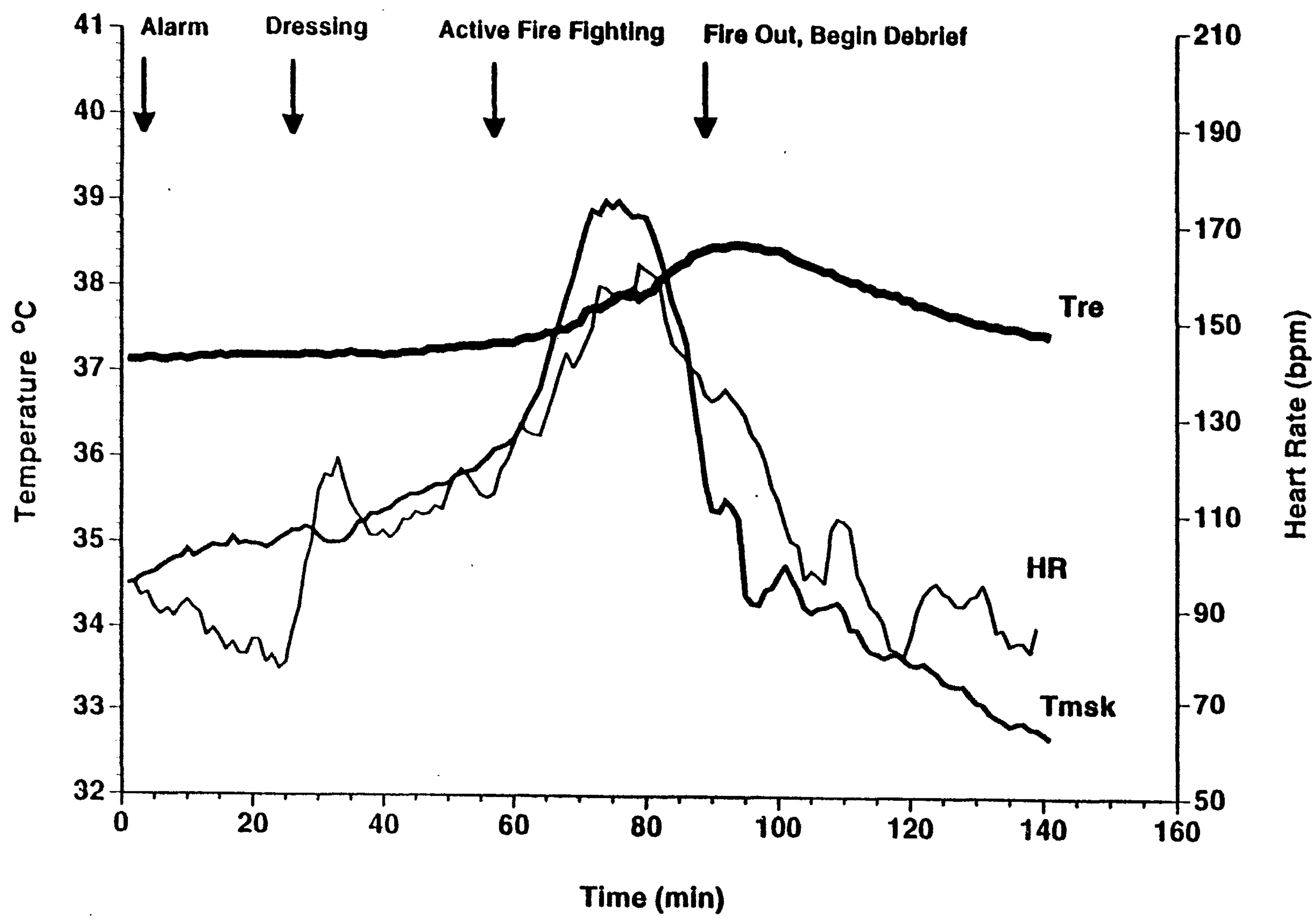

Fig. 4 Mean physiological responses for Day 2 (n=3).

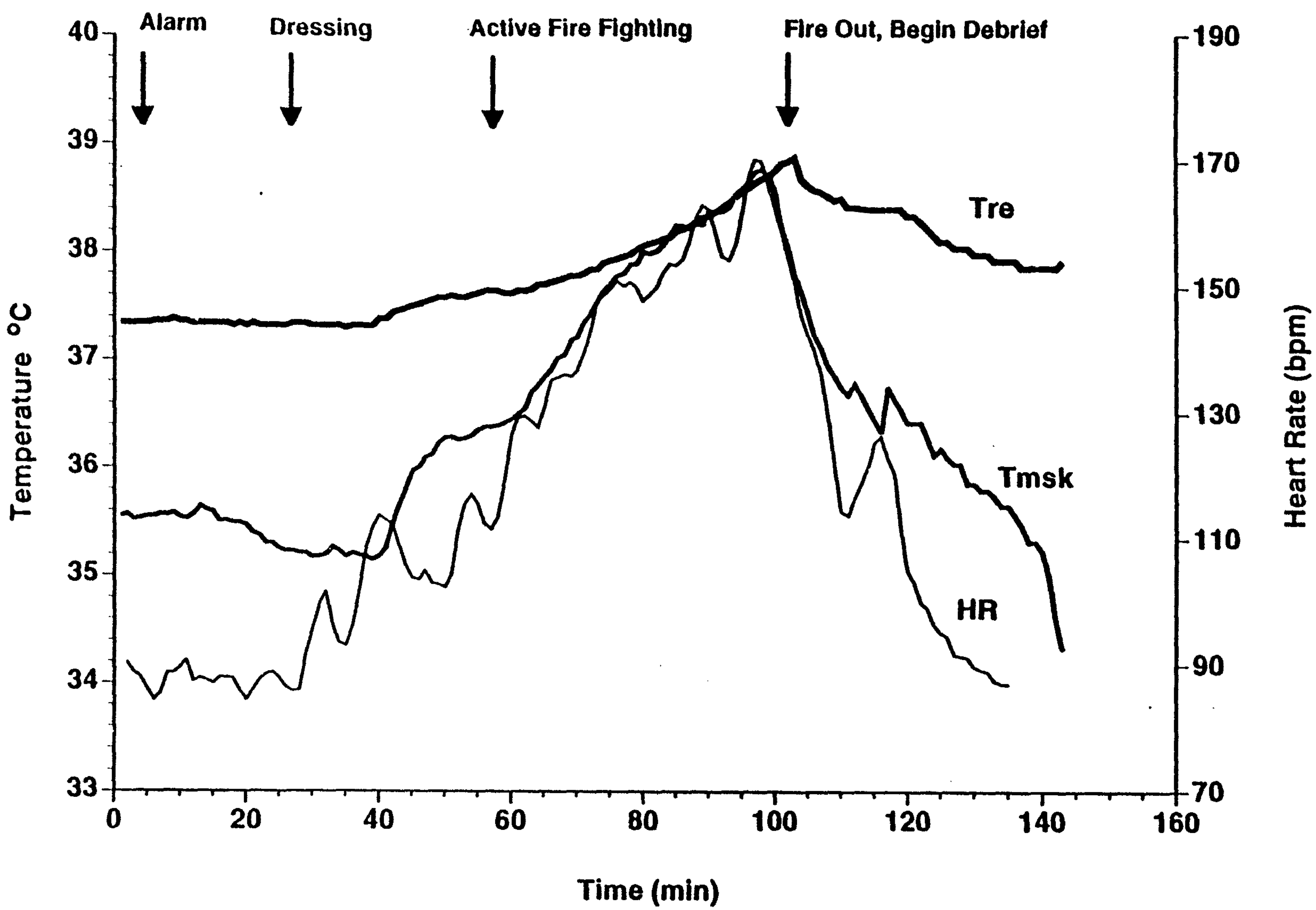

Fig. 5. Mean physiological responses for Day 3 (n=3).

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13. ABSTRACT *(Maximum 200 words)*

The findings from previous studies of men wearing firefighting clothing suggest a high potential for individual heat strain associated with firefighting. However, no study has determined the level of heat strain during actual firefighting conditions. Thus, the objective of this study was to determine the level of heat strain experienced by U.S. Navy personnel while combating fires aboard a fire research ship. Subject volunteers (n=9) were recorded for rectal and mean skin temperatures and heart rate during three fire test days. Air temperatures in the compartment containing the fire to be extinguished averaged 470 $\pm$ 170°C, while air temperatures in the compartment from which the fire was fought ranged from 40 to 125°C. Peak values for rectal temperature averaged 39.2 $\pm$ 1.0°C, while peak mean skin temperature averaged 39.5 $\pm$ 0.9°C. Peak body heat storage averaged 2.02 $\pm$ 0.77 kcal.kg^{-1} and peak heart rate averaged 186 $\pm$ 13 bpm. Our findings indicate that shipboard firefighting is associated with a remarkable level of individual heat strain. These findings have applications to operational training programs, generation of exposure guidelines, and development of heat strain countermeasures.

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